The cluster burn-up programme CCC and a comparison of its results with NPD experiments

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by

C.F. Højerup

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Abstract

This paper gives a brief description of the computer programme CCC, which can be used for rod/rod cluster burn up calculations. The paper also contains a comparison of CCC results with some Canadian measurements on NPD fuel.

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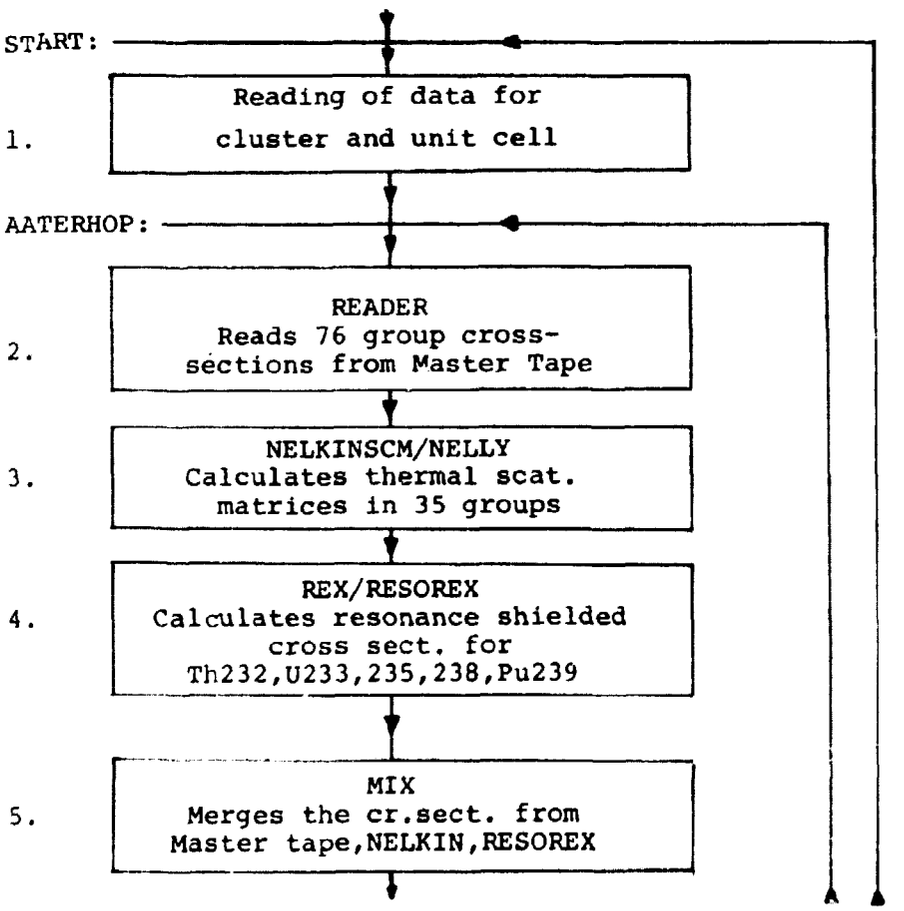
F. 25-204

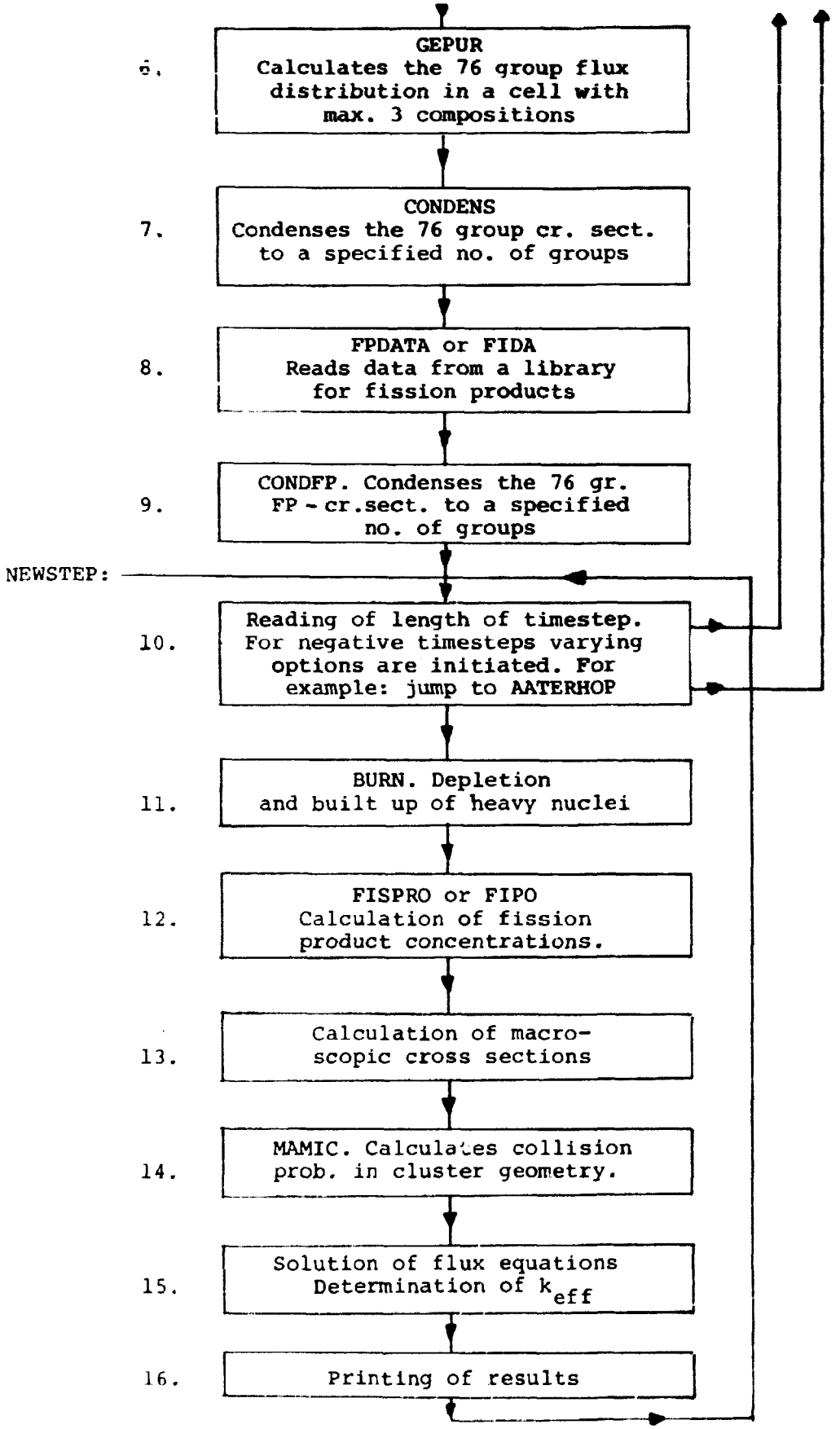
Introduction

This paper gives a brief description of the computer programme CCC, which can be used for rod/rod cluster burn up calculations. The paper also contains a comparison of CCC results with some Canadian measurements on NPD fuel.

1. CCC

CCC is an ALGOL programme, intended for use on a B 6700 computer. Essentially, it consists of two parts. The first part of the programme makes many (76) groups calculations on a unit cell (rod, clad, coolant) to provide spectra for the condensation of cross sections to fewer groups. The other part of the programme then performs flux- and burn up-calculations on the true cluster geometry in the fewer energy groups. A block diagram will show the way through it:




6.
GEPUR
Calculates the 76 group flux distribution in a cell with max. 3 compositions
7.
CONDENS
Condenses the 76 group cr. sect. to a specified no. of groups
8.
FPDATA or FIDA
Reads data from a library for fission products
9.
CONDFP. Condenses the 76 gr. FP - cr.sect. to a specified no. of groups
NEWSTEP:
10.
Reading of length of timestep. For negative timesteps varying options are initiated. For example: jump to AATERHOP
11.
BURN. Depletion and built up of heavy nuclei
12.
FISPRO or FIPO
Calculation of fission product concentrations.
13.
Calculation of macro-scopic cross sections
14.
MAMIC. Calculates collision prob. in cluster geometry.
15.
Solution of flux equations
Determination of k_{eff}
16.
Printing of results

Supplementary comments on the blocks:

1. A texted print-out example of input data is shown in app. 1.
2. READER
3. NELKINSCM/NELLY. Either of the two procedures calculates thermal scattering matrices according to Nelkins model for water and heavy water and according to the free gas model for all other nuclei. NELLY is a fast version operating with polynomials originally generated by means of NELKINSCM.
4. REX/RESOREX. Calculates resonance shielded cross sections and Dancoff factors for the various positions of fuel in the cluster. In the RESOREX library, tables are stored which allow determination of the cross sections of U 233, U 235 and Pu 239 in the presence of either Th 232 or U 238 as functions of the excess scattering cross section. If both Th 238 and U 238 are present, a weighted mean value is taken.
5. MIX.
6. GEPUR. In GEPUR the fluxdistribution in 76 groups of a unit cell consisting of up to 3 different materials (full, cladding, moderator) is calculated. The spatial resolution is set by machine capacity and time, but 10 concentric zones are quite feasible. For LWR's 3 zones are sufficient. Collision probabilities are used.
7. CONDENS. The cluster calculations, which the programme is approaching now, are made in a number of groups which is specified in the input. Very often, 10 groups are used, but any number $\leq$ 76 can be chosen. In CONDENS the 76 group cross sections are condensed to the new structure by means of the spectra (for fuel, cladding and moderater) calculated in GEPUR.
8. FPDATA or FIDA. Only one of these procedures is present at a time, and proper MERGE cards must be used to construct the correct coding. FPDATA and FIDA reads the fission product data to be used in FISPRO and FIPO, respectively.
9. CONDFP. Only present together with FPDATA and condenses the 76 group cross sections read by FPDATA to the chosen structure by means of the flux spectrum characterized by composition

number 1 in GEPUR.

10. Options. The length of the new timestep is read here. If the number read is negative, various routes are taken, thus:

DT = -1: GO TO START of a new problem.

-2<DT<-1: Uranium isotopes and Thorium are recycled, i.e. the contents of these isotopes in the various fuel positions are redistributed evenly, and the fission products are removed.

DT = -2: All the heavy nuclides (i.e. also Pu) are recycled.

-3<DT<-2: Pu recycling and addition of U 235 and U 238 (read in).

DT = -3: The information necessary to restart the programme from this point can be punched on cards.

DT = -4 The physical properties of the cluster i.e. temperatures and densities, of the various compositions, can be changed and the programme returns to the label AATERHOP, for starting new 76 groups calculations. The option is intended for calculation of coefficients (voids, temperature, etc.).

DT = -5: A new power level and a timestep length can be read. The option is useful f.ex. by Xe-transient studies.

DT = -6 A print-out of fission product activities is obtained. (For health physics purposes).

11. BURN. Depletion procedure for the actinides: Th 232, Pa 233, U 233, U 234, U 235, U 236, U 238, Np 239, Pu 239, Pu 240, Pu 241, Pu 242. 3 burnable poisons can also be treated in BURN, either as burning independently or as transforming into each other by capture.

12. FISPRO or FIPO. These are the procedures keeping account of the fission product concentrations. As in 8. only one of them can be present. FIPO/FIDA are equipped with a lo group cross section library and consequently requires this group system to be followed.
FISPRO/FPDATA/CONDFP can be used with any subsystem of the main 76 groups system.

13. -

14. **MAMIC. A procedure which calculates collision probabilities for the various regions of the cluster. In this connection, all the fuel in one ring of rods is one region, all the claddings around these rods form another region, and the coolant belonging to the rods constitutes yet another region.**

15. **The usual system of linear equations for the space-group fluxes is solved by a iterative procedure, SOLUTION, the same which was used in 6. GEPUR.**

16. **An example of the kind of results which are printed out is shown as app. 2.**

2. NPD Calculations

NPD is Canadas first nuclear power plant. It is a 80 MWth CANDU reactor with a 19 rod bundle. In fig. 1 is shown a cross section of the bundle. In an extensive experimental programme[*] several bundles have been examined, with exposures from 1000 MWd/tU to 11000 MWd/tU. Isotopic contents of U 235, U 238, Pu 239, Pu 240, Pu 241, Pu 242 and Nd 148 have been determined. The bundles have been taken from widely different positions in the reactor, so that spectra and power densities have varied considerably from bundle to bundle. The CCC calculations have not been extended to that degree of detailed follow-up, rather has a single bundle been studied in a power density of 2000 W/cm of bundle length, and a leakage corresponding to a buckling of 1.9 m^{-2}.

The input data example shown in app. 1 is for this NPD calculation, and app. 2 gives the start of the output of the same calculation.

The detailed comparison is shown in table 1 and figures 2, 3, 4, 5, 6, 7 and 8.

[*] Private communication from J. Griffiths of AECL

Fig. 2. Gives the U 235 concentration in the 3 rod positions and the average. It seems that in the calculations the centre rod and the first ring burn sligthly too fast, while the average, as could be expected, is quite satisfactory.

Fig. 3. shows the built up of Pu 239. At high exposures the agreement is quite bad between calculations and experiments, the former completely failing to reproduce the trends of the latter to diminish the difference between the 3 rod positions and even reverse the ratio of the centre rod to the 1. ring.

Fig. 4. shows a 4-5 pct. underestimation of Pu 240 built up, but the relative behaviour of the 3 rod positions is satisfactory, despite the disagreements of Pu 239.
The U 236 built up in fig. 5 shows an overestimation of the concentrations in all rod positions at high exposures. This is not consistent with the correct average removal rate of U 235 in fig. 2.

Fig. 6. shows good agreement for the Pu 241 concentration in the centre rod and 1. ring, while the 2. ring is some 10% underestimated.

The opposite, but consistent, picture comes out in fig. 7 for the Pu 242. Here the 2. ring is correct, but the centre rod and the 1. ring are overestimated by some 10%.

Finally, fig. 8 shows the concentration of the stable fission product Nd 148, which is a measure of the number of fissions. The agreement is very satisfactory, showing that the relative power production of the 3 rod positions is predicted correctly.

Conclusions

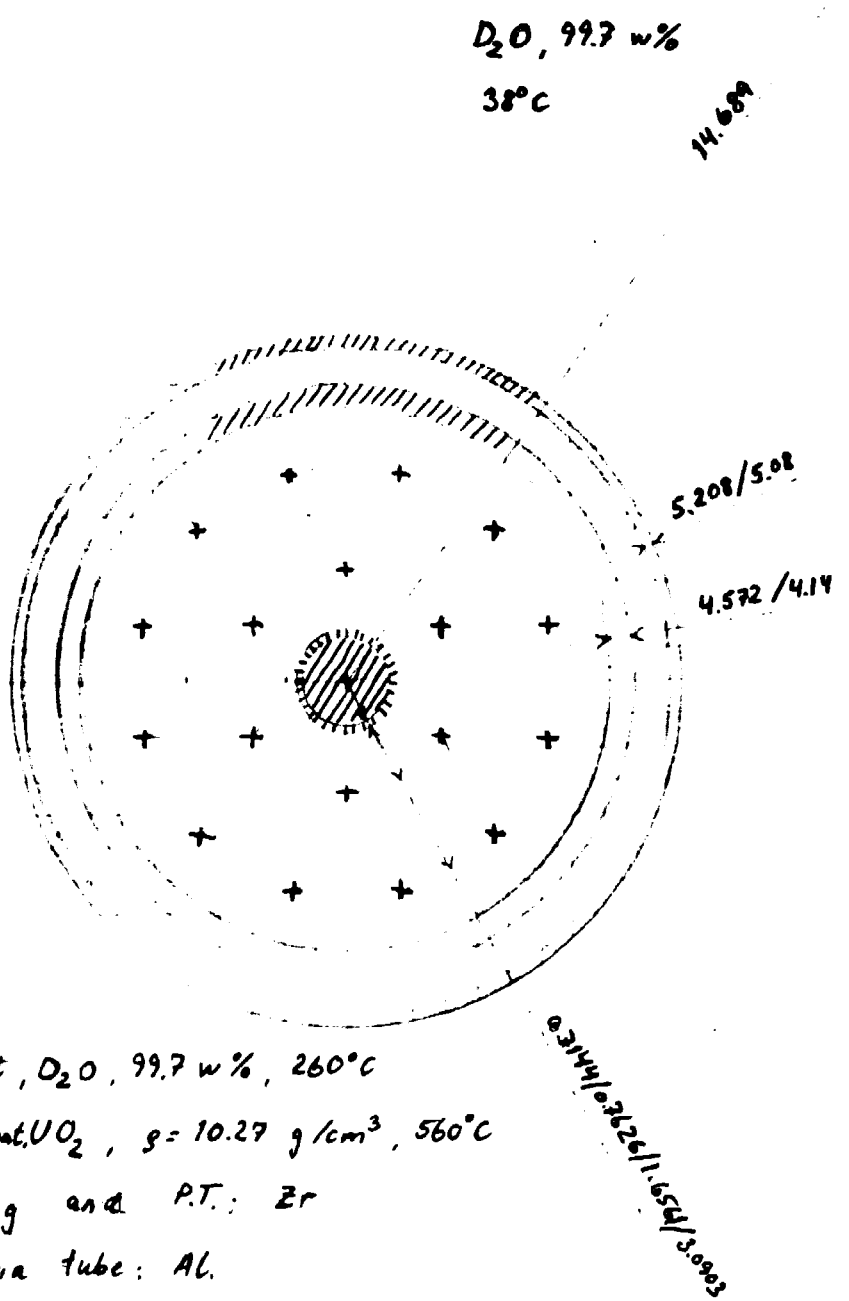
Although minor discrepancies are found for most isotopes and most rod positions, these are so small that they can be tolerated. The distribution and concentration of Pu 239 is badly predicted. In the experimental results the centre rod aquires a higher Pu 239 content than the rods in the 1. ring. This fact is difficult to give a qualitative explanation for, and is not at all reflected in the calculations.

Table 1.

Burn up		N235/N238%		N236/N238%		N239/N238%		N240/N239%		N241/N239%		N242/N239%		ND148/N238 (10^{-6})	
MWd/kg	Pos	CCC	Exp.	CCC	Exp.	CCC	Exp.	CCC	Exp.	CCC	Exp.	CCC	Exp.	CCC	Exp.
	1	.630	.6363	1.4_{10}-2	<.02	.0586	.0657	4.09	5.06	.20	.33	.005	.019	15.0	15.1
	2	.623	.6256	1.5_{10}-2	<.02	.0677	.0693	4.35	5.57	.22	.41	.006	.031	16.1	16.3
	3	.607	.6032	1.7_{10}-2	<.02	.0809	.0830	5.01	6.50	.27	.49	.008	.027	18.8	20.2
0.98	Av.	.613	.612	1.6_{10}-2	<.02	.0756	.078	4.78	6.17	.25	.46	.008	.028	17.7	18.7
	1	.587	.596	.021	.021	.0836	.0918	6.29	7.23	.44	.59	.018	.032	22.8	22.1
	2	.578	.586	.022	.023	.0963	.0946	6.68	7.84	.49	.69	.021	.036	24.6	23.6
	3	.555	.552	.025	.026	.1138	.1148	7.72	9.37	.61	.90	.030	.061	28.8	(29.3)
1.5	Av.	.564	.565	.024	.025	.107	.107	7.37	8.85	.56	.83	.027	.050	27.1	27.1
	1	.466	.484	.039	.037	.146	.160	13.4	13.6	1.68	1.66	.16	.13	48.7	46.5
	2	.451	.468	.042	.039	.166	.164	14.3	14.7	1.84	1.83	.18	.16	52.9	(46.5)
	3	.412	.420	.047	.047	.191	.186	16.6	17.5	2.30	2.47	.27	.27	62.0	60.4
3.25	Av.	.427	.438	.045	.044	.181	.178	15.8	16.5	2.14	2.24	.24	.22	58.4	55.3
	1	.368	.384	.054	.052	.185	.204	20.6	21.5	3.16	3.11	.49	.42	74.3	(67.5)
	2	.350	.363	.057	.059	.210	.211	22.0	23.1	3.44	3.45	.58	.54	81.1	78.9
	3	.304	.301	.064	.067	.235	.229	25.5	27.5	4.33	4.69	.87	.89	95.1	95.2
5.0	Av.	.322	.325	.061	.062	.224	.222	24.2	25.9	4.02	4.24	.77	.75	89.6	88.6
	1	.299	.309	.065	.065	.208	.234	26.9	28.6	4.50	4.57	.97	.87	96.3	97.7
	2	.280	.285	.068	.066	.234	.233	28.6	30.7	4.88	5.05	1.14	1.05	105.4	109.4
	3	.239	.223	.075	.078	.258	.248	33.0	36.4	6.14	6.98	1.73	1.88	124	125
6.5	Av.	.251	.247	.072	.074	.248	.242	31.4	34.3	5.69	6.29	1.52	1.58	116	119
	1	.245	.262	.073	.070	.223	.249	32.7	34.2	5.79	5.84	1.60	1.36	117	114
	2	.226	.238	.076	.074	.250	.243	34.8	36.6	6.27	6.45	1.88	1.66	128	121
	3	.180	.174	.083	.085	.271	.260	39.9	42.7	7.84	8.74	2.85	2.89	150	149
7.9	Av.	.198	.199	.080	.081	.262	.254	38.0	40.4	7.27	7.90	2.50	2.50	141	138
	1	.206	.226	.079	.076	.232	.256	37.7	38.6	6.91	6.85	2.29	1.76	133	131
	2	.187	.203	.082	.079	.259	.252	40.1	41.5	7.46	7.71	2.70	2.33	147	138
	3	.143	.143	.088	.088	.278	.265	45.5	47.8	9.25	10.23	4.06	3.90	173	168
9.1	Av.	.161	.166	.085	.085	.270	.261	43.5	45.4	8.61	9.26	3.56	3.31	163	156
	1	.160	.174	.086	.082	.241	.264	44.5	47.3	8.52	8.84	3.52	3.06	158	158
	2	.142	.156	.088	.087	.268	.268	47.2	49.3	9.19	9.42	4.13	3.51	175	165
	3	.103	.101	.094	.091	.285	.271	52.9	56.1	11.2	12.12	6.18	6.05	206	197
10.8	Av.	.119	.122	.092	.089	.277	.267	50.8	53.6	10.5	11.14	5.43	5.11	194	185

FIG. 1.

NPD - bundle



Coolant, D_2O, 99.7 w%, 260°C

Fuel: nat. UO_2, ρ = 10.27 g/cm^3, 560°C

Cladding and P.T.: Zr

Calandria tube: Al.

End fittings equiv.: 47.9 cm^3 Zr, 25 cm^3 coolant

Bundle/active length: 49.53/48.4734

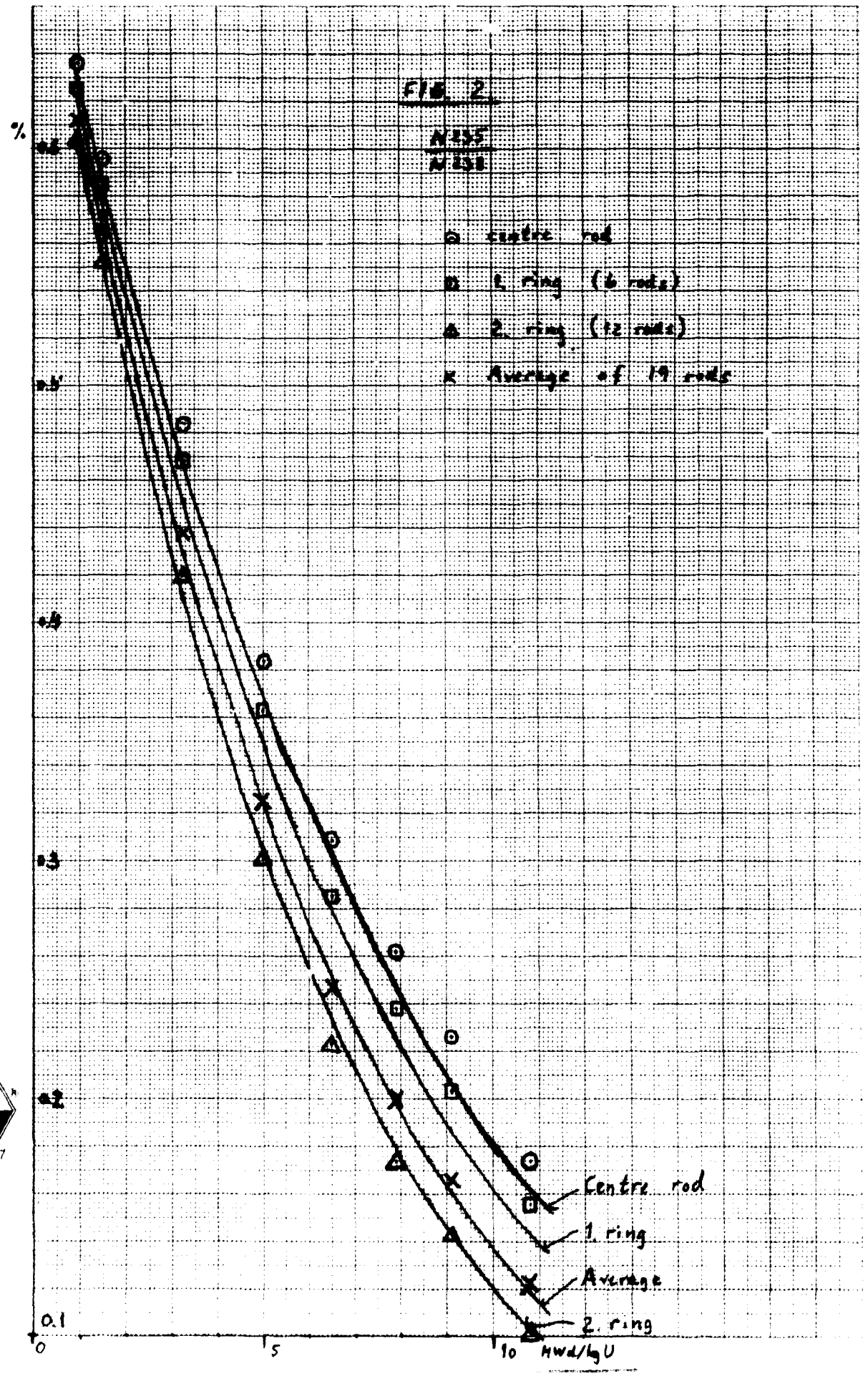


Fig. 2
N235
N238
% 1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5
10 MWd/kg U
Centre rod
1. ring
Average
2. ring

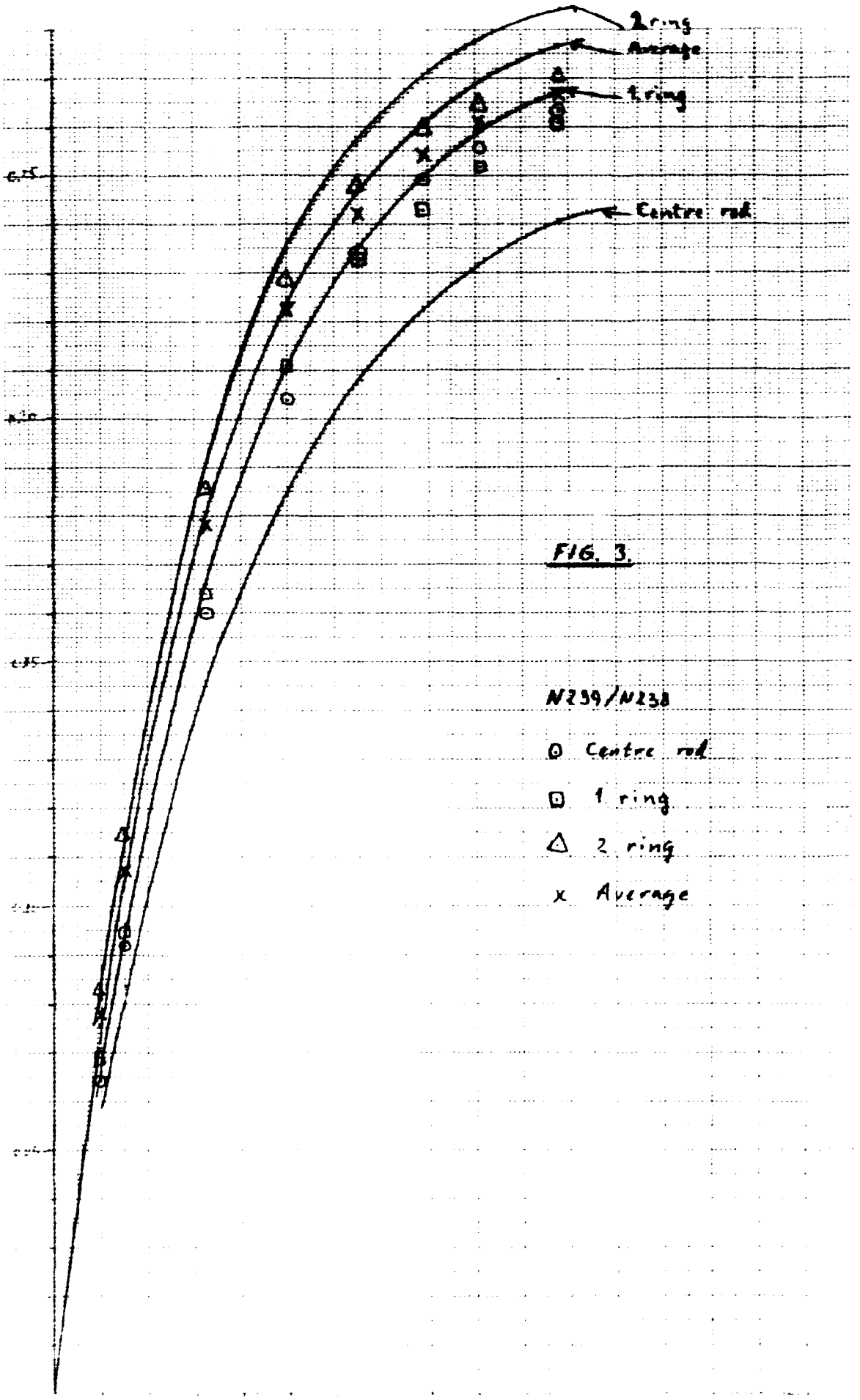

2 ring
Average
1 ring
Centre rod
6,75
6,50
6,25
N239/N238
Centre rod
1 ring
2 ring
Average

FIG. 3.

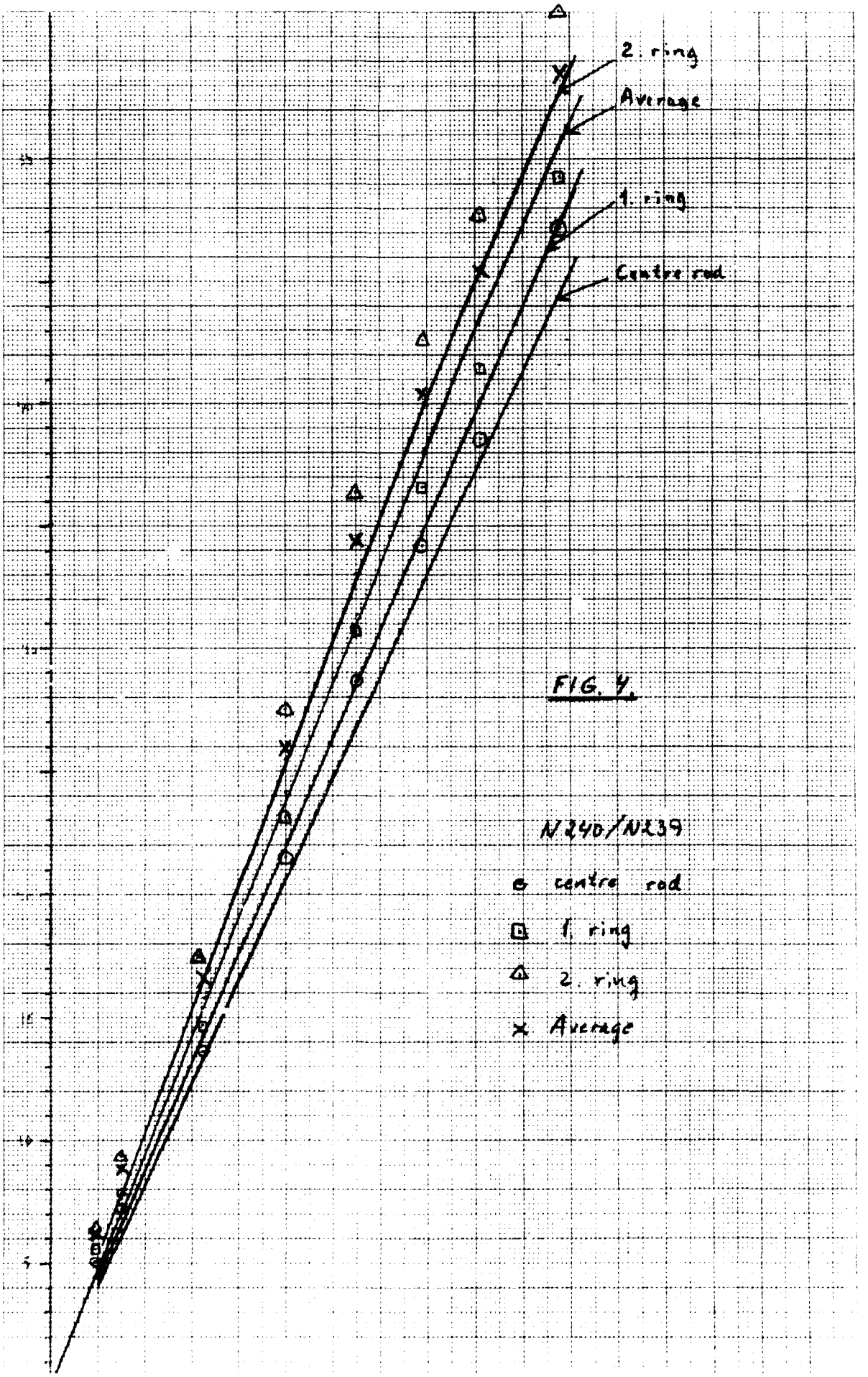


FIG. 4.

N240/N239

- centre rod
- 1. ring
- 2. ring
- Average

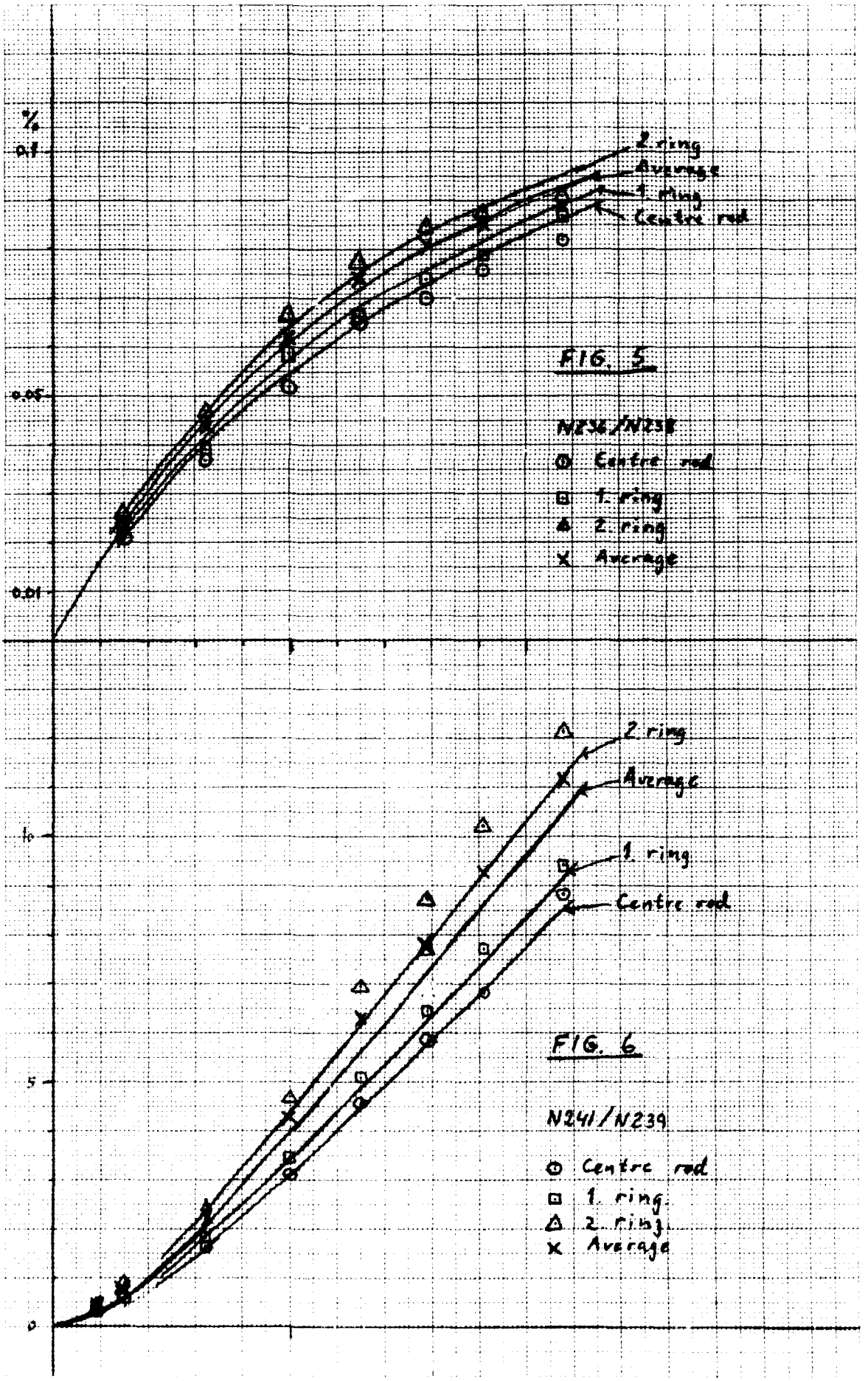
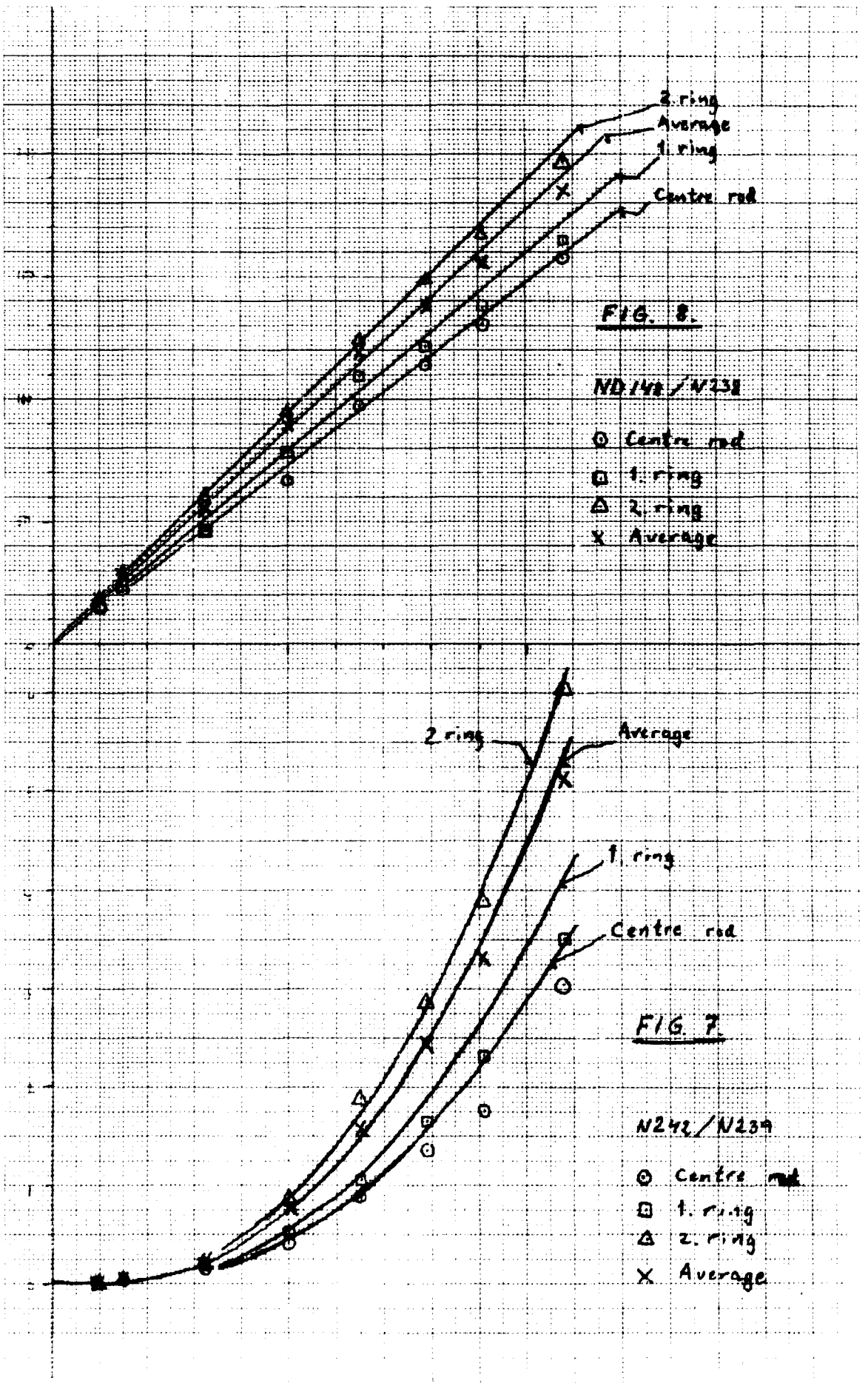


FIG. 5

FIG. 6


2 ring
Average
1 ring
Centre rod
FIG. 8.
ND142 / N238
⊙ Centre rod
□ 1. ring
△ 2. ring
X Average
2 ring
Average
1 ring
Centre rod
FIG 7.
N242 / N239
⊙ Centre rod
□ 1. ring
△ 2. ring
X Average

App. I.

Print out of input data

Example

```
 ***NPD EXP. RESULTS. VERIFICATION OF CCC?                                    ***
CRS                    ALK PROGRAM NO. 603 - UPGAVE NO.    1.          24.   8.1976.


   NC    NR    NF    NT    NG NTHG  RTP  RUP  BPP  BR1  BR2  BR3
    0    13    19    27    10     6    0    1    1    0    0    0
 NTEMP NREST   NRG
     3     1    12
PRINTER=     7
CARDS OUT=       0          1          2
MEANS        NO PUNCH  SYNTPUNDATA  HICPUNDATA
CARDS OUT=     0
VOIDFRACTION=      0.00000
RESTART=                 0          1          2          3
MEANS   NO READ.NO PUNCH  NO READ.PUNCH     READ.PUNCH   READ.NO PUNCH
RESTART=     0
MAX. NUMB. OF SUBREGIONS =    3.

NO. OF SUBREGIONS=     1   R=          0.71440   IND=     0
COMPOSITION NUMBER=    1

NO. OF SUBREGIONS=     1   R=          0.76260   IND=     2
COMPOSITION NUMBER=    4

NO. OF SUBREGIONS=     1   R=          0.84970   IND=     1
COMPOSITION NUMBER=    7

NO. OF SUBREGIONS=     3   R=          2.51760   IND=     3
NO. OF  PODS=     6
RSUB.IND:          0.71440     0
COMPOSITION NUMBER=    2
RSUB.IND:          0.76260     2
COMPOSITION NUMBER=    4
IND:       1
COMPOSITION NUMBER=    7

NO. OF SUBREGIONS=     3   R=          4.14000   IND=     3
NO. OF  PODS=    12
RSUB.IND:          0.71440     0
COMPOSITION NUMBER=    3
RSUB.IND:          0.76260     2
COMPOSITION NUMBER=    4
IND:       1
COMPOSITION NUMBER=    7

NO. OF SUBREGIONS=     1   R=          4.57200   IND=     2
COMPOSITION NUMBER=    5

NO. OF SUBREGIONS=     1   R=          5.20800   IND=     2
COMPOSITION NUMBER=    6

NO. OF SUBREGIONS=     1   R=          6.00000   IND=     1
COMPOSITION NUMBER=    6

NO. OF SUBREGIONS=     1   R=          7.25000   IND=     1
COMPOSITION NUMBER=    6

NO. OF SUBREGIONS=     1   R=          8.75000   IND=     1
COMPOSITION NUMBER=    6
```

Data to define cluster geometry

```
NO. OF SUBREGIONS=     1    R=          10.50000    IND=     1
COMPOSITION NUMBER=    6

NO. OF SUBREGIONS=     1    R=          12.50000    IND=     1
COMPOSITION NUMBER=    6

NO. OF SUBREGIONS=     1    R=          14.66900    IND=     1
COMPOSITION NUMBER=    6

 FUEL COMPOSITIONS:  1=FUEL, 0=NON-FUEL
   1    1    1    0    0    0    0    0
```

Identification no. of nuclei

```
 IDNO:      5       536       7       539       9      10      11      12      19      15      28      31
 IDNO:     41        31      42        41      31
```

°K

```
 TEMP:  833.00   833.00   833.00   833.00   833.00  833.00  833.00  833.00  833.00  833.00  833.00  833.00
 TEMP:  533.00   533.00   311.00   311.00   311.00
```

= WELLY
= WELRIN
SCM

```
 NURN:      2        2        2        2        2       2       2       2       2       2       2       1
 NURN:      2        1        2        2        1
```

```
COMPOSITION NUMBER     1
NEWDATA=     1
ND: 1.63600E-04 0.          2.27460E-02 0.          0.          0.          0.          0.          0.
ND: 0.          4.58200E-02
```

```
COMPOSITION NUMBER     2   (= comp. no. 1)
NEWDATA=    -1
```

```
COMPOSITION NUMBER     3   (= comp. no. 1)
NEWDATA=    -1
```

```
COMPOSITION NUMBER     4
NEWDATA=     1
ND: 3.08250E-02 0.          0.          0.          0.          0.          0.          0.
```

```
COMPOSITION NUMBER     5
NEWDATA=     1
ND: 2.68800E-02 0.          0.          0.          0.          0.          0.          0.
```

```
COMPOSITION NUMBER     6
NEWDATA=     1
ND: 0.          1.30340E-02 0.          0.          0.          0.          0.          0.
```

Diluted Al

```
COMPOSITION NUMBER     7
NEWDATA=     1
ND: 0.          0.          5.31950E-02 1.60100E-04 2.66777E-02 0.          0.          0.
```

D H O — coolant

```
COMPOSITION NUMBER     8
NEWDATA=     1
ND: 0.          0.          0.          0.          0.          6.74190E-02 2.02800E-04 3.38110E-02
```

Moderator

```
BG2  = 1.900E-04   cm^-2
MASS = 1.451E+01   gr U/cm of rod
POWER= 2.000E+03   w/cm of cluster
```

```
 ***NPD EXP. RESULTS. VERIFICATION OF CCC?                                    ***
CRS                  AEK PROGRAM NO. 603 - OPGAVE NO.    1.          24.   8.1976.

DATA TO DEFINE UNIT CELL FOR 76 GROUP SPECTRUM CALCULATION (IN 3 COMPOSITIONS)

NM
    12     5     3

                 NO      NTEMP     THERSC      TEMP
                  5          1          2     833.0
                536          1          2     833.0
                  7          1          2     833.0
                539          1          2     833.0
                  9          1          2     833.0
                 10          1          2     833.0
                 11          1          2     833.0
                 12          1          2     833.0
                 19          1          2     833.0
                 15          1          2     833.0
                 28          1          2     833.0
                 31          3          1     833.0
                                        1     533.0
                                        1     311.0
                 36          1          2     533.0
                 35          1          2     533.0
                 42          2          2     533.0
                                        2     311.0
                 41          2          2     533.0
                                        2     311.0
Not input
Redit
  0.          1.000000E+00 2.300000E+00 2.800000E+00 3.111400E+00 4.000000E+00 5.208000E+00 6.000000E+00 7.2500
 1.050000E+01 1.250000E+01 1.466900E+01
CPN
    1     1     1     1     2     2     3     3     3     3
    3     3
COMPOSITION NO.     1
REGM
          5           536             7           539             9            10            11            12
         28            31
REGT
          1             1             1             1             1             1             1             1
          1             1
```

```
RLGD
 1.63600E-04 0.          2.27460E-02 0.          0.          0.          0.          0.          0.
 0.          4.58200E-02
COMPOSITION NO.     2
RLGM
          36          35          42          41          31
RLGT
           1           1           1           1           2
RLGD
 1.37650E-02 4.65230E-03 1.85900E-02 5.59500E-05 9.32310E-03
COMPOSITION NO.     3
RLGM
          42          41          31
RLGT
           2           2           3
RLGD
 6.74190E-02 2.02800E-04 3.32110E-02
  GR IN ALL GROUPS=    1.00000
ENERGY STRUCTURE=      -1 ⟶ The 10 groups FIPD-structure
UPPER RESONANCE GROUP=      4
FUEL TEMPERATURE=       633.00

FUEL, CLADDING AND MODERATOR SWELL FOR RESONANCE    0.71440         1.19500         3.37000
TIME IN PREPDA     :      PROCESS =  0.064 MIN
                          ELAPSED =  0.012 MIN
                          IN/OUT  =  0.006 MIN
```

The 10 groups FIPD-structure

App. II.

Print out of results

Example

```
***NPD EXP. RESULTS. VERIFICATION OF CCCP                                    ***
CRS                  AEK PROGRAM NR. 603 - UPGAVE NO.    1.        24.   8.1976.


TIME IN READER    :      PROCESS =   0.130 MIN
                         ELAPSED =   0.276 MIN
                         IN/OUT  =   0.165 MIN


TIME IN      ISOCH :     PROCESS =   1.385 MIN
                         ELAPSED =   1.696 MIN
                         IN/OUT  =   0.143 MIN


RESOREX CALCULATION:
 U238 BASED
FUEL ASSUMED OXIDE.
DANCOFF FACTOR FOR BLACK REGION  1= 0.05229
DANCOFF FACTOR FOR BLACK REGION  2= 0.29619
DANCOFF FACTOR FOR BLACK REGION  3= 0.67427
TOTAL DANCOFF FACTOR= 0.52214
SUGGESTED DANCOFF FACTOR FOR COPPER ROD= 0.81551

RESONANCE ESCAPE: 8.89337E-01
TH232 BASED
FUEL ASSUMED OXIDE.

RESONANCE ESCAPE: 9.05855E-01
TIME IN REX       :      PROCESS =   0.183 MIN
                         ELAPSED =   0.263 MIN
                         IN/OUT  =   0.022 MIN


TIME IN MIX       :      PROCESS =   0.534 MIN
                         ELAPSED =   1.281 MIN
                         IN/OUT  =   0.809 MIN
```

54.	190.	193.	198.	203.	208.	212.	215.	219.	223.	227.	229.	231.
55.	227.	231.	237.	243.	249.	254.	258.	263.	268.	272.	275.	276.
56.	227.	231.	237.	243.	250.	255.	259.	264.	268.	272.	275.	276.
57.	213.	216.	221.	225.	230.	234.	237.	240.	244.	247.	250.	251.
58.	191.	193.	197.	199.	202.	204.	205.	208.	211.	213.	215.	216.
59.	149.	150.	152.	154.	155.	155.	156.	157.	159.	161.	162.	163.
60.	92.	93.	94.	95.	95.	95.	95.	95.	96.	97.	98.	98.
61.	54.	54.	55.	55.	55.	55.	55.	55.	56.	56.	57.	57.
62.	119.	120.	121.	122.	121.	121.	120.	121.	122.	123.	124.	124.
63.	138.	139.	141.	141.	140.	140.	139.	139.	140.	142.	143.	143.
64.	214.	216.	218.	219.	218.	217.	215.	215.	217.	219.	221.	222.
65.	639.	649.	665.	676.	684.	688.	685.	690.	700.	712.	721.	727.
66.	1163.	1197.	1256.	1311.	1367.	1406.	1423.	1454.	1495.	1534.	1564.	1579.
67.	2097.	2188.	2358.	2528.	2715.	2852.	2937.	3046.	3170.	3280.	3362.	3403.
68.	3370.	3569.	3949.	4343.	4787.	5124.	5360.	5641.	5932.	6180.	6360.	6449.
69.	4433.	4772.	5433.	6134.	6941.	7568.	8056.	8578.	9105.	9539.	9848.	9999.
70.	3094.	3388.	3970.	4602.	5338.	5908.	6366.	6843.	7310.	7686.	7953.	8083.
71.	2735.	3045.	3670.	4362.	5180.	5809.	6321.	6851.	7362.	7769.	8050.	8188.
72.	1994.	2268.	2833.	3478.	4253.	4847.	5341.	5850.	6329.	6702.	6956.	7080.
73.	1140.	1337.	1755.	2251.	2862.	3326.	3720.	4122.	4489.	4768.	4955.	5046.
74.	462.	567.	803.	1101.	1481.	1763.	2000.	2248.	2463.	2622.	2727.	2778.
75.	109.	143.	228.	348.	510.	626.	727.	825.	907.	966.	1005.	1023.
76.	9.	13.	25.	46.	79.	101.	121.	139.	152.	162.	169.	172.
---- R	50.	150.	240.	296.	356.	460.	560.	663.	800.	963.	1150.	1359.

ABSORPTION IN

COMPOSITION NO. 1: 85.65132 PCT
COMPOSITION NO. 2: 6.13524 PCT
COMPOSITION NO. 3: 8.21344 PCT
KINF = 1.1089
KEFF = 1.0389
TIME IN GEPUR : PROCESS = 4.607 MIN
ELAPSED = 5.438 MIN
IN/OUT = 0.014 MIN

TIME IN CONDENS : PROCESS = 0.282 MIN
ELAPSED = 0.466 MIN
IN/OUT = 0.146 MIN
TIME IN FPDATA : PROCESS = 0.698 MIN
ELAPSED = 0.991 MIN
IN/OUT = 0.195 MIN
TIME IN FPCOND : PROCESS = 0.024 MIN
ELAPSED = 0.096 MIN
IN/OUT = 0.000 MIN

16 groups flux distribution for condensation of cross sections.

```
***NPD EXP. RESULTS. VERIFICATION OF CCCP                                    ***
CRS                ALK  PROGRAM NO. 603  - LPGAVE NO.    1.          24.  8.1976.
```

Initial cluster calculation

```
 IRRADIATION TIME :=          0.000    DAYS
NEUTRON FLUX
GROUP:    2       3       4       5       6       7       8       9      10
REGION:   1:
  53902 46663   9382 19536   1675    290   1866   4382  55894  28045
REGION:   2:
  50152 46319   9420 19620   1682    292   1874   4395  57098  29599
REGION:   3:
  48927 46258   9456 19675   1684    292   1878   4400  57598  30312
REGION:   4:
  50677 44248   9266 19344   1699    294   1899   4434  58936  30893
  46957 43540   9325 19489   1699    296   1901   4449  60577  32973
  45007 43157   9371 19576   1915    298   1907   4456  61405  34112
REGION:   5:
  43055 38819   9260 20254   1956    304   1943   4536  66021  38449
  38686 38009   9336 20452   1969    306   1956   4564  67921  41068
  36376 37573   9386 20583   1975    308   1962   4578  68760  42503
REGION:   6:
  27251 32901   9562 24654   2027    317   2009   4689  74786  50308
REGION:   7:
  22467 30844   9747 22389   2049    321   2029   4626  77112  53038
REGION:   8:
  17825 28927   9916 22899   2073    325   2050   4647  79726  57076
REGION:   9:
  12319 25137   9695 23476   2110    331   2084   4699  84997  63821
REGION:  10:
   8081 21044   9120 23782   2139    336   2112   4756  90515  69918
REGION:  11:
   5353 17611   8433 23006   2152    338   2128   4801  95129  74538
REGION:  12:
   3779 15201   7846 23093   2155    339   2135   4830  98414  77626
REGION:  13:
   3217 14108   7541 23587   2153    339   2135   4841  99990  79089

AVERAGE:
   9681 20021   8424 23296   2123    333   2102   4767  91926  70369

AVERAGE IN FUEL:
  45985 40946   9268 19992   1935    300   1922   4496  63251  35515
```

		ABSORPTION	FISSION
COMPOSITION NO.	1:	4.01430	4.47791 PCT
COMPOSITION NO.	2:	26.62951	28.72064 PCT
COMPOSITION NO.	3:	63.38604	66.80145 PCT
COMPOSITION NO.	4:	0.75838	0.00000 PCT
COMPOSITION NO.	5:	1.70533	0.00000 PCT
COMPOSITION NO.	6:	1.33340	0.00000 PCT
COMPOSITION NO.	7:	0.05745	0.00000 PCT
COMPOSITION NO.	8:	2.41558	0.00000 PCT

COMPOSITION	BURN UP EFFS. CYCLE MWD/TU	BURNUP TOTAL MWD/TU
1	0.00	0.00

centre rod
clad
coolant
rods, clad, cool } 1 ring
rods, clad, cool } 2 ring
Pressure tube
calandria tube + airgap
} Moderator regions

```
          2              0.00                0.00
          3              0.00                0.00

    AVERAGE              0.00                0.00

 NUMBER DENSITIES
U235,U236:
  1.6360E-04   1.6360E-04   1.6360E-04   1.6360E-04
  0.           0.           0.           0.
U238,NP,PU239,PU240,PU241,PU242:
  2.2746E-02   2.2746E-02   2.2746E-02   2.2746E-02
  0.           0.           0.           0.
  0.           0.           0.           0.
  0.           0.           0.           0.
  0.           0.           0.           0.
  0.           0.           0.           0.
 N235/N238 PCT:        0.7192       0.7192       0.7192       0.7192
 N236/N238 PCT:        0.0000       0.0000       0.0000       0.0000
 N239/N238 PCT:        0.0000       0.0000       0.0000       0.0000
 N240/N239 PCT:        0.0000       0.0000       0.0000       0.0000
 N241/N239 PCT:        0.0000       0.0000       0.0000       0.0000
 N242/N239 PCT:        0.0000       0.0000       0.0000       0.0000
ND148/N238 PPM:        0.0000       0.0000       0.0000       0.0000

INTEGRAL RHO*DBU                                          =      0.00000
FISSION NEUTRONS PER THERMAL NEUTRON ABSORBED IN FUEL,ETA=      1.29760
FAST FISSION FACTOR,                                  EPS=      1.01787
RESONANCE ESCAPE PROBABILITY,                         P   =      0.90880
THERMAL UTILIZATION,                                  F   =      0.93895
INFINITE MULTIPLICATION FACTOR                      KINF=      1.12712
  FINITE MULTIPLICATION FACTOR                      KEFF=      1.05497
SLOWING DOWN AREA,                                   TAU=    108.59523
DIFFUSION AREA,                                      L**2=   246.31534
MATERIAL BUCKLING,                                   BM**2= 3.58187E-04
DIFFUSION COEFFICIENTS                                    : 1.29424E+00 8.72117E-01
DIFFUSION MATRIX                                          : 1.19181E-02 0.            1.03937E-02 3.54065
REPRODUCTION CROSS SECTIONS                               : 8.14633E-04 4.31412E-03
FISSION CROSS SECTIONS                                    : 3.04021E-04 1.77506E-03
FLUXES                                                    : 1.71577E+13 4.79405E+13

EL.TIME=       652.70  SEC.
CP.TIME=       483.68  SEC.
IO.TIME=        84.35  SEC.
```

ad hoc printout

Accumulated times

1. Timestep

TIMESTEP=
5.000
IRRADIATION TIME I= 5.000 DAYS
ABSORPTION IN FISSION PRODUCTS:

2.72046E-08 1.74894E-07 1.00297E-06 9.68693E-06 8.76812E-06 2.07995E-05 2.79869E-05 1.52226E-04 3.07

ABSORPTION IN FISSION PRODUCTS:

2.90275E-08 1.86582E-07 1.07015E-06 1.02011E-05 9.21321E-06 2.18651E-05 2.91449E-05 1.56789E-04 3.94

ABSORPTION IN FISSION PRODUCTS:

3.36068E-08 2.15762E-07 1.23644E-06 1.18777E-05 1.03052E-05 2.44701E-05 3.19179E-05 1.67436E-04 4.07

NEUTRON FLUX

GROUP	1	2	3	4	5	6	7	8	9	10
REGION	1:									
	53702	47315	9515	19805	1931	294	1890	4399	54934	27522
REGION	2:									
	50820	46968	9553	19848	1937	296	1899	4414	56168	29080
REGION	3:									
	49583	46907	9566	19944	1919	295	1903	4420	56679	29792
REGION	4:									
	51363	44870	9397	19611	1929	298	1914	4454	58029	30386
	47597	44155	9457	20038	1936	306	1926	4471	59714	32483
	45624	43766	9503	20249	1942	312	1933	4488	60603	33619
REGION	5:									
	43674	39373	9391	20531	1965	306	1969	4564	65261	37995
	39230	38551	9468	20934	1990	311	1982	4574	67121	40642
	36894	38109	9521	21169	2002	312	1989	4579	68089	42088
REGION	6:									
	27640	33371	9698	22154	2055	321	2036	4647	74268	49672
REGION	7:									
	22786	31284	9885	22697	2077	325	2056	4668	76665	52728
REGION	8:									
	18078	29339	10058	23214	2101	329	2078	4692	79344	56794
REGION	9:									
	12493	25495	9832	23602	2139	335	2112	4748	84727	63603
REGION	10:									
	8195	21343	9249	24110	2166	340	2141	4809	90351	69767
REGION	11:									
	5428	17861	8552	24136	2132	343	2156	4857	95048	74044
REGION	12:									
	3832	15416	7957	24020	2184	344	2164	4886	98388	77572
REGION	13:									
	3261	14307	7647	23914	2182	343	2165	4898	99999	79056
AVERAGE:										
	9817	20305	8543	23618	2152	338	2131	4819	91769	70237
AVERAGE IN FUEL:										
	46630	41527	9309	20260	1961	304	1948	4520	62434	35041

	ABSORPTION	FISSION
COMPOSITION NO. 11	3.99884	4.66153 PCT

```
COMPOSITION NO.     2:      26.56520          20.66225 PCT
COMPOSITION NO.     3:      63.25039          66.87622 PCT
COMPOSITION NO.     4:       0.4433            0.00000 PCT
COMPOSITION NO.     5:       1.67805           0.00000 PCT
COMPOSITION NO.     6:       1.36660           0.00000 PCT
COMPOSITION NO.     7:       0.05657           0.00000 PCT
COMPOSITION NO.     8:       2.37994           0.00000 PCT

COMPOSITION      NUMBER OF FPDS. CYCLE     BURNUP TOTAL
                      MWD/TU                  MWD/TU
            1          30.74                   30.74
            2          32.92                   32.92
            3          38.41                   38.41

     AVERAGE           34.27                   34.27

 NUMBER DENSITIES
U235.U236:
  1.6278E-04   1.6271E-04   1.6251E-04   1.6192E-04
  1.2759E-07   1.3679E-07   1.5045E-07   1.5129E-07
U238.NP239.PU240.PU241.PU242:
  2.2745E-02   2.2745E-02   2.2745E-02   2.2745E-02
  3.0129E-07   3.6497E-07   4.6497E-07   3.0497E-07
  2.6629E-07   3.0911E-07   4.2501E-07   3.4689E-07
  3.3755E-10   4.1592E-10   5.2750E-10   5.1-07E-10
  6.1251E-13   7.8266E-13   1.1067E-12   1.0275E-12
  6.5151E-16   8.8620E-16   1.3-00E-15   1.2942E-16
 U235/U238 PCT:          0.7157          0.7154          0.7147          0.7150
 N236/U238 PCT:          0.0006          0.0006          0.0007          0.0007
 N239/U238 PCT:          0.0025          0.0029          0.0035          0.0033
 N240/U239 PCT:          0.0049          0.0031          0.0022          0.0041
 N241/U239 PCT:          0.0001          0.0001          0.0001          0.0001
 N242/U239 PCT:          0.0000          0.0000          0.0000          0.0000
ND148/U238 PPM:          0.0000          0.0000          0.0001         14.8679

INTEGRAL RHO*ORO                                                  =      1.41972
FISSION NEUTRONS PER THERMAL NEUTRON ABSORBED IN FUEL.ETA=      1.25761
FAST FISSION FACTOR.                                      EPS=      1.01975
RESONANCE ESCAPE PROBABILITY.                             P   =      0.90495
THERMAL UTILIZATION.                                      F   =      0.94015
INFINITE MULTIPLICATION FACTOR                            KINF=      1.09591
  FINITE MULTIPLICATION FACTOR                            KEFF=      1.02650
SLOWING DOWN AREA.                                        TAU=    108.61563
DIFFUSION AREA.                                           L**2=    242.26585
MATERIAL BUCKLING.                                        B**2=  2.73348E-04
DIFFUSION COEFFICIENTS                                    :  1.29425E+00  8.72066E-01
DIFFUSION MATRIX                                          :  1.19159E-02  0.                1.03917E-02  3.59763E
REPRODUCTION CROSS SECTIONS                               :  8.13939E-04  8.25609E-03
FISSION CROSS SECTIONS                                    :  3.03762E-04  1.74987E-03
FLUXES                                                    :  1.76356E+13  4.85456E+13

EL.TIME=       714.45  SEC.
CP.TIME=       524.72  SEC.
IO.TIME=        84.00  SEC.
```

etc.